

An impact assessment of alien invasive plants in South Africa generally dispersed by native avian species

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Abstract

Invasive alien plant species have been identified as a major threat to biodiversity and the relationship with native avian dispersers may increase their invasion potential. The impact of invasive plant species needs to be quantified using comparable assessment tools across different habitats and species to allocate limited resources to high-priority species. Here, we used the Generic Impact Scoring System (GISS) to assess the impacts of 16 fleshy-fruited alien invasive plant species in South Africa generally dispersed by native avian species. The results showed that fleshy-fruited invasive species have both environmental and socio-economic impacts. The cumulated impact scores for lantana (*Lantana camara*) and the tree of heaven (*Ailanthus altissima*) were the highest, with scores of 42 and 32, respectively. Some species, such as white mulberry (*Morus alba*), camphor tree (*Cinnamomum camphora*), American bramble (*Rubus cuneifolius*) and Brazilian pepper tree (*Schinus terebinthifolius*), had low overall impact scores of 8, 18, 14 and 16, respectively, but scored the maximum impact of 5 for certain mechanisms. Environmental impacts of fleshy-fruited invasive plant species had a high impact magnitude through effects on the ecosystem and vegetation. Socio-economic impacts were mainly through effects on forest production, agriculture and human health. Species with large crop sizes, small seeds and fruit sizes had higher environmental and socio-economic impact magnitude. The information generated in this study is important for guiding resource allocation and preventing the uncontrolled introduction of invasive species in South Africa. The impact of the fleshy-fruited invasive species transcended sectors and, therefore, effective management of invasive species will require the collaboration of multiple and inter-sectoral stakeholders in South Africa.

Keywords

environmental impacts, GISS, impact score, management strategy, NEMBA, socio-economic impacts

Introduction

Invasive alien plants have been identified as a major threat to biodiversity (Gosper and Vivian-Smith 2009; Liu et al. 2017). Depending on the species, invasive alien plants generally reduce species richness (Gaertner et al. 2009), disrupt pollination and dispersal networks (Pyšek et al. 2012), change ecosystem functioning (Andersen et al. 2004; Charles and Dukes 2008), cause economic losses (Novoa et al. 2016; Zengeya et al. 2017) and impact human well-being (Vilà et al. 2011). Invasive alien plant species are introduced either accidentally or intentionally for forestry, agriculture, horticulture (Arriaga et al. 2004), recreation (van Wilgen et al. 2008), restoration (Kumschick et al. 2012) and as ornamentals (Hulme et al. 2018). New introductions or movements of invasive alien plant species within a country are promoted by increased domestic and global travel and trade, making their management a challenge in many countries (Leung et al. 2012; Seebens 2019). Once introduced, invasive alien plants that attract and rely on generalist frugivores for seed dispersal thrive because animal-plant interactions allow for fast recruitment (Jordaan et al. 2011a, b, 2012; Molefe et al. 2020; Traveset and Richardson 2020). The spread of invasive alien plants is further exacerbated by global climate change (Ahmad et al. 2019a, b; Mofu et al. 2019). For frugivore dispersed plant species in South Africa, altered habitats trigger and sustain invasions (Bitani et al. 2020).

Like other parts of the world, South Africa is severely affected by alien plant invasion (Nel et al. 2004; McLean et al. 2018). Alien plant species are the country's most widespread and damaging group of invasives and have been reported to cover approximately 7% of the country (van Wilgen 2018). Amongst invasive alien plants, those with fleshy fruits have high-risk invasiveness (Jordaan et al. 2011b). Species traits have been shown to influence invasiveness (the likelihood of a species being introduced and spreading). Generalist birds have been identified as the most important seed dispersers of fleshy-fruited invasive shrubs and trees (Richardson and Rejmanek 2011). In new habitats, fleshy-fruited invasive alien plants overcome barriers of spread through seed dispersal mutualisms (Aslan and Rejmanek 2011; Jordaan et al. 2011a, b). Bird-plant interactions are equally important to avian dispersers as they gain a nutritious supplementary fruit source (Thabethe et al. 2015; Blendinger et al. 2016). The invasion process and success of avian-dispersed invasive alien plants are influenced by plant morphological (Gosper and Vivian-Smith 2009), chemical (Jordaan and Downs 2012; Blendinger et al. 2016) and phenological traits (Marciniak et al. 2020; Nogueira et al. 2020). Certain traits favour bird-fruit interaction and allow plants to integrate into native seed-dispersal networks (Rojas et al. 2019; Marciniak et al. 2020). For example, plants that produce large fruit crop sizes have a high potential to be consumed by birds (Blendinger and Villegas 2011).

Impacts associated with invasives vary across habitats and taxa (Hawkins et al. 2015; Bacher et al. 2018), but are mainly related to changes to natural environments, society and economy (Jeschke et al. 2014; Measey et al. 2016; Kumschick et al. 2017). Consequently, impacts associated with biological invasions have led to the development of impact assessment tools intending to quantify the impacts posed by alien invasive species (Nentwig et al. 2016; Rumlerová et al. 2016; Bartz and Kowarik 2019). The impact assessment tools are based on scientific evidence (Kumschick et al. 2015; Moshobane et al. 2019), comparable across different regions and taxa (Nentwig et al. 2016) and allow for the synthesis of impact data (Vilà et al. 2019). Several tools have been developed. The two widely used ones are the Environmental Impact Classification for Alien Taxa (EICAT), developed by Blackburn et al. (2014) to quantify environmental impacts and the Generic Impact Scoring System (GISS), developed to assess environmental and economic impacts (Turbé et al. 2017). The GISS has been used for various taxa, including birds (Turbé et al. 2017; Shivambu et al. 2020), mammals (Hagen and Kumschick 2018), amphibians (Measey et al. 2016), fish (Orfinger and Gooddng 2018), arthropods (Laverty et al. 2015) and selected plants (Novoa et al. 2016; Yazlik et al. 2018). Using impact quantifying approaches like the GISS gives insights into which species are detrimental so that management prioritises those species with major impacts (Rumlerová et al. 2016) and provides information for decisions relating to the introduction of species (Bartz and Kowarik 2019).

As part of the global biodiversity goals, most countries worldwide are committed to preventing the introduction of high-priority species or minimising their impacts (Moshobane et al. 2019; Verbrugge et al. 2019). The Department of Environmental Affairs (DEA, now Department of Environment, Forestry & Fisheries, DEFF), through the South African National Biodiversity Institute (SANBI), aims to eventually conduct an impact assessment for all listed species as invasive under the National Environmental Management Biodiversity Act (NEMBA). Of the 379 listed terrestrial invasive plant species, only 75 plant species have been assessed (DEA 2016). Assessing the impacts posed by listed species is important to ensure that the listing can be challenged (SANBI 2017). In response to policy-makers' information needs, we aimed to assess the ecological and socio-economic impacts posed by selected fleshy-fruited invasive plant species dispersed by native avian species in South Africa. Additionally, we explored how morphological traits of fleshy-fruited invasive plants relate to their impacts. The results from the present study will assist in providing information for decision-making, allocating resources to control alien invasive plant species and identifying less-studied plants and impacts. In addition, where the study species have not yet been introduced, it will help guide decisions around permitting or prohibiting activities.

Methods

Species selection and literature search

Sixteen fleshy-fruited alien trees or shrubs dispersed by native avian species that occur in the coastal forests of KwaZulu-Natal, South Africa, were selected for this study. The selected plants are listed as invasive under the South African NEMBA. A literature survey, based on published scientific literature and e-literature from Google Scholar (<https://scholar.google.com>) and Web of Science – ISI Web of Knowledge (<https://apps.webofknowledge.com>) and the global invasive species database, such as the Global Invasive Species Database (GISD: www.iucngisd.org/gisd) and the Invasive Species Specialist Group (ISSG: www.iucngisd.org/gisd), was conducted before assessing the risk posed by the species. For each species, species' common names, scientific names and synonyms were used to search for the literature and filter the search by the information provided in the abstracts and titles. In addition, we used terms like "invasive alien plants", "fleshy-fruited", "IAS", "introduced plant species", "non-indigenous plants", "ecological impacts", "economic impacts" and "negative impacts" to search for papers. All the references of the selected publication were screened and included as grey literature.

Impact assessments

Different impact assessment tools have been developed to quantify the impacts of invasive species (Nentwig et al. 2016; Nkuna et al. 2018). For this study, we used the Generic Impact Scoring System (GISS) as it integrates both ecological and socio-economic impacts (Nentwig et al. 2016) and has proven to be useful in assessing the impacts of invasive plants globally, including in South Africa (e.g. Novoa et al. 2016; Nkuna et al. 2018; Shivambu et al. 2020). The GISS is divided into two main categories, environmental and socio-economic impacts, each with six different mechanisms. The environmental impacts consist of impacts (1.1) on plants or vegetation, (1.2) on animals, (1.3) through competition, (1.4) through disease transmission, (1.5) through hybridisation and (1.6) on the ecosystem. The socio-economic include impacts on (2.1) agricultural production, (2.2) animal production, (2.3) forestry production, (2.4) human infrastructure (2.5) human health and (2.6) human social life. For each category, the impact level ranges from 0 (no known impacts or data deficiency) – 5 (highest impact) and the scenarios are described to ensure consistency (details on Nentwig et al. 2016). The overall impact scores (environmental and socio-economic) per species were used for analyses.

Traits of plants

Plant and fruit morphological traits influencing the invasion success of fleshy-fruited invasive alien plants are well documented. For each of the plant species, we compiled data that included mean fruit size, seed size, number of fruits and crop size (Suppl. material 1).

Data analyses

The differences between the overall and mean impact scores for each species' socio-economic and environmental impacts were tested using a paired t-test. We tested the differences between the mechanisms for environmental and socio-economic impact for each plant species using ANOVA. We used Kendall's rank correlation to test the correlation between the overall impact scores per plant and the number of papers used for each species. To explore the effects of plant species' functional traits with the environmental and socio-economic impact (sum of the six mechanisms), we fitted linear mixed-effects models. The functional trait data were log-transformed because of the non-normal distribution. We used the package lme4, library nlme and function lme in R with the plant species traits as explanatory variables and the impacts as the response variable. To account for the phylogenetic relatedness, the species family was specified as a random effect (random ~ 1 | a). All the data were analysed using R statistical analysis v.3.4.4 (R Core Team 2018).

Results

A total of 103 publications were used to score the impacts of 16 fleshy-fruited invasive plant species. There was no significant difference between the overall environmental and socio-economic impacts (Welch's t.test: $P = 0.42$). Amongst the 16 invasive plant species, lantana (*L. camara*) (impact magnitude = 42) and the tree of heaven (*A. altissima*) (impact magnitude = 32) had the highest cumulated impact scores (Table 1). Environmental impacts scores were higher for lantana and the camphor tree (*Cinnamomum camphora*) than the other species (Table 1). The highest socio-economic impact scores were recorded for lantana and tree of heaven (Fig. 1). Four plant species that had relatively little environmental impact presently included guava (*Psidium guajava*), inkberry (*Cestrum laevigatum*), the forget-me-not-tree (*Duranta erecta*) and the wax tree (*Rhus succedanea*). Two species that had no socio-economic impacts were coral bush (*Ardisia crenata*) and white mulberry (*Morus alba*). The tree of heaven scored the maximum impact on the socio-economic category through human social life (i.e. loss of recreational activities and tourist attractions, see Nentwig et al. 2016; Table 2). Some species showed low overall impact scores, but scored higher (the maximum impact score of five) in some mechanisms, for example, *M. alba* (impacts through hybridisation), *C. camphora* (impacts on plants or vegetation), *R. cuneifolius* (impacts on ecosystems) and *S. terebinthifolius* (impacts on plant or vegetation) (Fig. 1; Table 2). Most of the impacts recorded for the socio-economic category were through animal production, agricultural production and human health and the least impact was on human infrastructure (Fig. 2a; Table 2). There was a non-significant negative relationship between the environmental impact score and mean seed size and a significant relationship with mean fruit size (Fig. 3; Table 3). There was a non-

Table 1. The sum of environmental and socio-economic impacts scored for 16 fleshy-fruited invasive plant species using the Generic Impact Scoring System (GISS). Species that scored a maximum impact score of 5 in any of the mechanisms are highlighted in bold.

Scientific names	Common names	NEMBA category	GISS score		Total	Region of origin
			Environmental	Socio-economic		
<i>Ailanthus altissima</i>	Tree of heaven	1b	13	19	32	Asia (China)
<i>Ardisia crenata</i>	Coral bush	1b	3	0	3	Asia
<i>Cestrum laevigatum</i>	Inkberry	1b	0	3	3	South America (Brazil)
<i>Cinnamomum camphor</i>	Camphor tree	1b	16	2	18	East Asia
<i>Duranta erecta</i>	Forget-me-not-tree	3	0	1	1	America
<i>Eugenia uniflora</i>	Surinam cherry	1a	2	2	4	South America (Brazil)
<i>Lantana camara</i>	Lantana	1b	23	19	42	Central and South America
<i>Melia azedarach</i>	Syringa	1b	3	2	5	Asia, Australia
<i>Morus alba</i>	White mulberry	2	8	0	8	Asia
<i>Psidium guajava</i>	Guava	2	0	6	6	America
<i>Toxicodendron succedanea</i>	Wax tree	1	0	3	3	Asia
<i>Ricinus communis</i>	Castor-oil plant	1b	4	2	6	Africa
<i>Rubus cuneifolius</i>	American bramble	1b	10	4	14	North America
<i>Schinus terebinthifolius</i>	Brazilian pepper tree	1b	11	5	16	South America (Brazil)
<i>Solanum mauritianum</i>	Bugweed	1b	12	7	19	South America
<i>Syzygium jambos</i>	Rose apple	3	5	6	11	South - East Asia

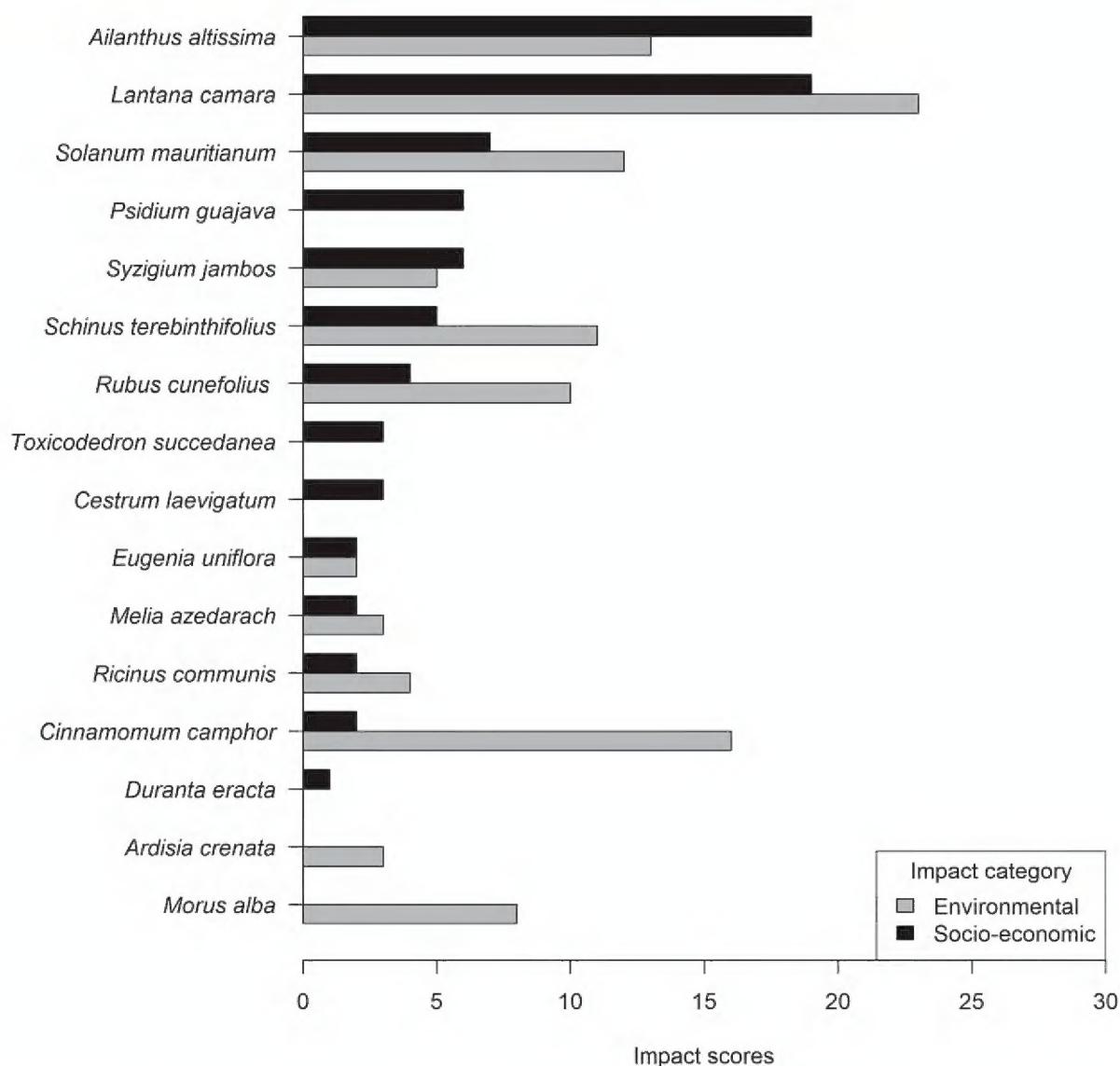


Figure 1. Impact scores for the socio-economic and environmental impact category for all the sixteen fleshy-fruited invasive plant species in South Africa in the present study.

Table 2. Environmental and socio-economic mechanism impact scores of fleshy-fruited invasive plant species assessed using the Generic Impact Score System (GISS).

Species	Common names	Environmental mechanisms						Socio-economic mechanisms						Overall scores	Number of literature
		Plants or vegetation	Animals	Competition	Diseases transmission	Hybridization	Ecosystems	Agricultural production	Animal production	Forestry production	Human Infrastructure	Human health	Human social life		
<i>Ailanthus altissima</i>	Tree of heaven	4	3	2	0	0	4	13	3	0	4	4	3	19	32
<i>Ardisia crenata</i>	Coral bush	3	0	0	0	0	0	3	0	0	0	0	0	0	3
<i>Cestrum laevigatum</i>	Inkberry	0	0	0	0	0	0	0	3	0	0	0	0	3	3
<i>Cinnamomum camphor</i>	Camphor tree	5	3	2	3	0	3	16	0	0	0	0	2	2	18
<i>Duranta erecta</i>	Forget-me-not-tree	0	0	0	0	0	0	0	0	0	0	0	1	1	1
<i>Eugenia uniflora</i>	Surinam cherry	0	0	0	2	0	0	2	2	0	0	0	0	2	4
<i>Lantana camara</i>	Lantana	4	4	3	4	4	4	23	4	4	4	0	4	19	42
<i>Melia azedarach</i>	Syringa	0	0	0	0	0	3	3	0	0	0	0	2	2	5
<i>Morus alba</i>	White mulberry	0	0	0	3	5	0	8	0	0	0	0	0	0	8
<i>Psidium guajava</i>	Guava	0	0	0	0	0	0	0	3	0	3	0	0	6	6
<i>Rhus succedanea</i>	Wax tree	0	0	0	0	0	0	0	0	0	0	0	3	3	3
<i>Ricinus communis</i>	Castor-oil plant	3	1	0	0	0	0	4	0	0	0	0	2	2	6
<i>Rubus cuneifolius</i>	American bramble	3	0	2	0	0	5	10	0	2	2	0	0	4	14
<i>Schinus terebinthifolius</i>	Brazilian pepper tree	5	3	0	0	0	3	11	0	0	2	0	3	5	16
<i>Solanum mauritianum</i>	Bugweed	3	3	0	2	0	4	12	3	0	3	0	1	7	19
<i>Syzgium jambos</i>	Rose apple	0	0	2	3	0	0	5	3	0	3	0	0	6	11

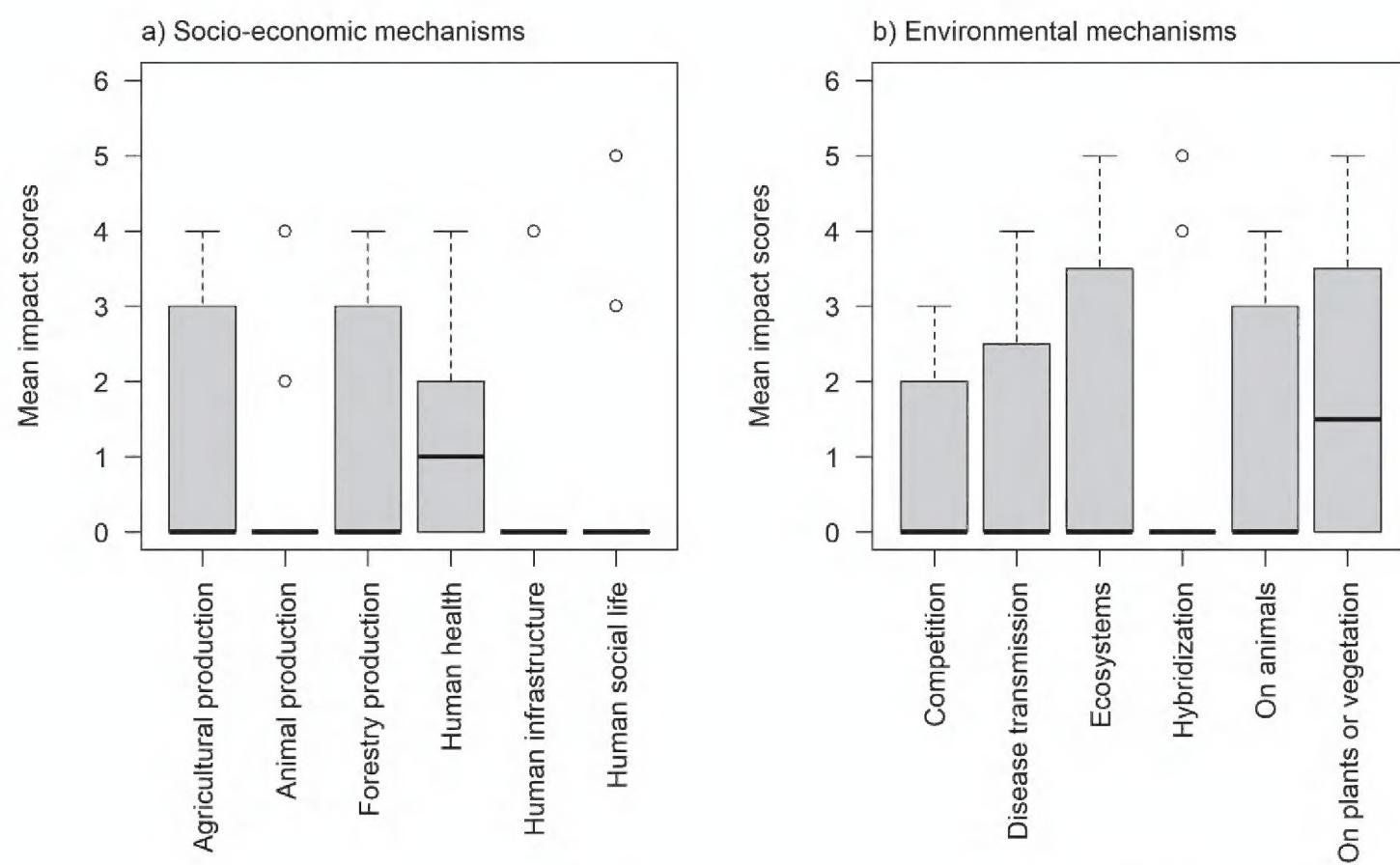


Figure 2. The mean impact scores for **a** the socio-economic mechanisms and **b** the environmental mechanisms in South Africa in the present study. (The boxes represent the mean impacts score in quantiles and the circles represent outliers).

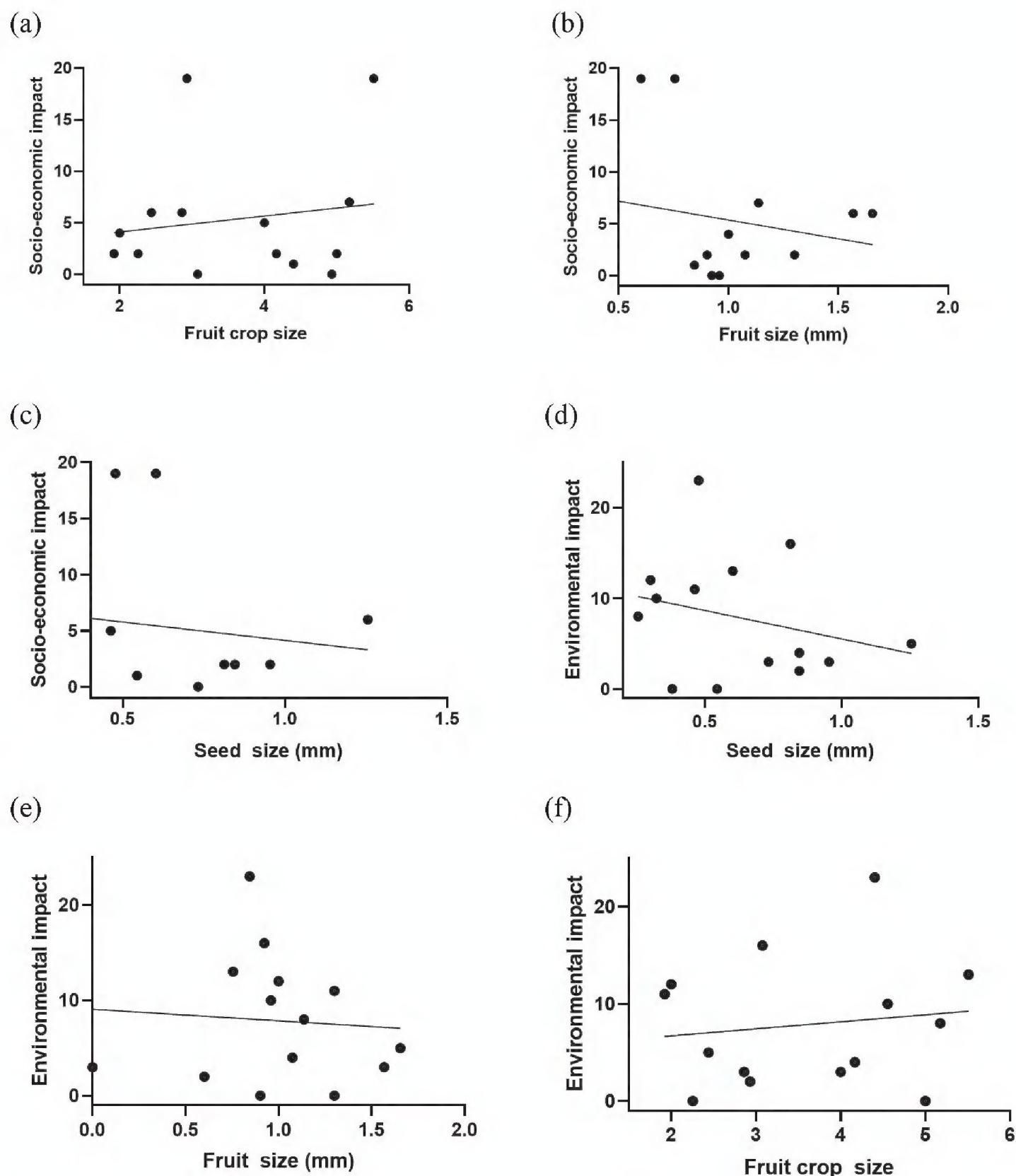


Figure 3. Relationship between socio-economic impacts with log-transformed morphological traits **a** mean fruit crop size **b** mean fruit size **c** mean seed size and environmental impacts with log-transformed morphological traits **d** mean seed size **e** mean fruit size and **f** mean fruit crop size. (Each dot represents a species).

significant positive relationship between socio-economic impact and crop size and a positive non-significant for mean seed size and mean fruit size (Fig. 3; Table 3).

Most environmental impacts were through impacts on plants or vegetation, ecosystem and animals and the least impacts were through hybridisation (Fig. 2b; Table 2). There were no significant differences in the impact magnitude of different mechanisms

Table 3. Linear mixed-effects model estimating the effect of fruit size, seed size and fruit crop size on the socio-economic and environmental impacts of avian dispersed alien invasive plant species in the current study. AIC is the Akaike Information Criterion.

Response	Model	Df	AICc	Log likelihood	P-value
Socio-economic impact					
	Log fruit size	12	93.17	-41.59	0.40
	Log seed size	12	92.91	-41.45	0.60
	Log fruit crop size	12	95.83	-42.92	0.59
Environmental impact					
	Log fruit size	12	91.72	-40.86	0.04*
	Log seed size	12	94.10	-42.05	0.34
	Log fruit crop size	12	96.71	-43.36	0.27

in both categories: socio-economic (ANOVA: $df = 5$, $P > 0.05$) and environmental (ANOVA: $df = 5$, $P > 0.05$, Fig. 2). We found that 14 (86%) of the 16 plant species had no records of causing socio-economic impacts through impacting human life and environmental impacts through hybridisation. Most records of alien invasive plant species were mainly for environmental rather than socio-economic mechanisms. The total number of papers used for the impact assessment was 103 (see Suppl. material 1 for a list of the data sources used) and there were significant differences between the number of papers and the scored impacts per plant (Kendall's Tau: $\tau = -0.15$; $p < 0.05$).

Discussion

In the present study, global impacts assessment of 16 fleshy-fruited invasive species indicated that 12 species had environmental impacts and 14 had socio-economic impacts. A total of six species in the present study showed either no environmental or socio-economic impacts. Similarly, a previous study in Europe that assessed the impacts of alien invasive plant species using the GISS showed no environmental or socio-economic impacts (Rumlerová et al. 2016). This is a consequence of studies focusing on certain impacts or the selection of species with already known impacts (Pyšek et al. 2012; Rumlerová et al. 2016; Schirmel et al. 2016; White et al. 2019). Previous studies have noted the influence of undocumented or lack of peer-reviewed information in quantitative impact assessment studies (McGeoch et al. 2012; Moshobane et al. 2019; Verbrugge et al. 2019). For example, *P. guajava* has major ecological impacts in Zululand, KwaZulu-Natal, South Africa, where this species has displaced native vegetation (C.T. Downs, unpublished data). Consequently, the impacts on the ecosystem or vegetation posed by this species are misrepresented in the present study. This highlights the importance of re-assessing the impacts of species once data are available or published in the case of using assessment tools that use peer-reviewed literature.

In the environmental category, we found impacts associated with fleshy-fruited invasive plant species were through the ecosystems, plants or vegetation impact mechanism and some species had the highest impact scores on these mechanisms,

for example, *R. cuneifolius*, *S. terebinthifolius* and *C. camphora*. These results correspond with previous studies showing similar findings on environmental impact mechanisms associated with invasive plant species (Vilà et al. 2011; Yazlik et al. 2018). For species with high scores, impacts on ecosystem functioning manifest in different ways, including integrating into ecosystem networks and changing seed dispersal and pollination networks which are important ecological processes. Through seed mutualism interaction, fleshy-fruited invasive plants alter the dispersal of other plant species and outcompete indigenous plants for dispersal agents (Mokotjomela et al. 2016). Consequently, changes in seed dispersal networks reduce overall biodiversity (Fuster et al. 2019) through the loss of ecological processes like pollination and seed dispersal. For example, in South Africa, *R. cuneifolius* alters pollination networks of native communities (Hansen et al. 2018) and disrupts bird-mediated ecological processes (Reynolds and Symes 2013). Some of the species with major impacts (i.e. *A. altissima*, *L. camara* and *S. terebinthifolius*) had impacts on vegetation and plants through allelopathy, negatively affecting native threatened plant species and overall biodiversity (Morgan and Overholt 2005; Sharma et al. 2005; Kowarik and Samuel 2007).

Impacts on human health, forestry and agricultural production were the main socio-economic impact mechanisms associated with fleshy-fruited invasive species in the present study, with *L. camara* and *A. altissima* having the highest impacts. Similarly, a study in Turkey showed that socio-economic impact mechanisms are through agriculture and human health (Yazlik et al. 2018). The major impact on forestry production may be because forests are identified as an important introduction pathway for many invasive tree and shrub species (Rejmánek 2014; Sitzia et al. 2016). Although some of these species are forest-edge species, they must be included in forest management (Sitzia et al. 2016). Impacts on agriculture and human health were indirect through hosting pests that damage agricultural crops or threaten human health. For example, *L. camara* harbours pests (e.g. tsetse fly *Glossina* spp.), resulting in major health issues in sub-Saharan Africa (Goulson and Derwent 2004). Additionally, alien fleshy-fruited plants form thick stands that generally reduce agricultural land's productivity and viability, resulting in reduced crop production of economically-important plants and increased management costs (Shackleton et al. 2017). It is important that the management of invasive plants is not only targeting protected areas and should be implemented in agricultural areas, as impacts associated with invasive plants are both environmental and socio-economic (Yazlik et al. 2018). This is particularly important for sub-Saharan African countries with agriculture-dominated economies, where livestock and crop farming constitute the largest agricultural sector (Pratt et al. 2017). Fleshy-fruited invasive species had relatively few or generally lower impacts on human infrastructure, except for *A. altissima*, which scored the maximum impact. This is mainly because the impacts of alien plant species on human infrastructure (e.g. roads, and traffic infrastructure, see Nentwig et al. 2016) remain poorly explored. Some species in the present study had low overall impact scores, but had the highest magnitude score for some mechanisms, for

example, *M. alba*, *C. camphora* and *R. cuneifolius*. In the United States of America (USA), *M. alba* has been reported to hybridise with an endangered native species *M. rubra* (Burgess et al. 2005), *C. camphora* replaces an endangered shrub *Ziziphus celata* in Florida, USA (Kaufman and Kaufman 2013) and *R. cuneifolius* threatens a grassland specialist plant in South Africa (Hansen et al. 2018). Similarly, a study that assessed the impacts of grasses using the GISS showed similar results where two grass species with low overall impact had high magnitude scores for certain mechanisms (Nkuna et al. 2018). This is particularly interesting as it raises an important question should species with high overall impact scores be considered as high priority or should species with low overall impact scores, but high magnitude scores for certain mechanisms, be of concern (Nkuna et al. 2018)? The overall impact scores can be useful in broad recommendations, but may negate the importance of specific species with specific impacts.

In the present study, there were significant differences between the scored impacts and the number of papers used; well-studied plant species scored significantly higher impacts than species with few or no impact studies. In general, the negative impacts of some species, especially those with economic value (i.e. *P. guajava*, *R. communis* and *R. cuneifolius*), are often overlooked because of their beneficial uses. The research efforts of assessing the impacts of economically-important invasive plants are potentially complicated by the trade-off between economic importance and their damage, resulting in misrepresentation of impacts. Indeed, Zengeya et al. (2017) assessed the impacts and benefits of invasive species and showed that the management of *P. guajava* has resulted in stakeholder conflict in South Africa because of the economic and intrinsic value of the plant. In addition, it has been reported that species with major economic impacts attract scientific attention, improving understanding of their ecological impacts (Pyšek and Richardson 2010). It was not the aim of this study to assess the limitations of this tool. Therefore, both scientists and decision-makers who aim to manage alien invasive species should consider both the benefits and costs of preventing the introduction of species with high impact scores or their management after introduction and establishment. This problem highlights the need for further studies to evaluate the socio-economic and ecological impacts posed by fleshy-fruited invasive plant species. Evaluating invasive species' social impacts will increase stakeholder engagement and scientific citizenship (Estévez et al. 2014; Crowley et al. 2017; Potgieter et al. 2019).

Species traits are important in the invasion success of alien plants (Pyšek and Richardson 2008). Our results of the impact relationship with morphological traits showed that species that produce large fruit crops of small fruit with small seed sizes have relatively higher environmental and socio-economic impacts. In cases where dispersal is limited to frugivores, fleshy-fruited plant species with large crop sizes are competitive, attract most species and are successful invaders (Ramaswami et al. 2017). For example, *S. mauritianum* has higher visitation rates than native and other plants alien to South Africa with relatively small crop sizes (Mokotjomela et al. 2013). Therefore, plant traits that influence seed dispersal interaction and invasion success are important and should

be incorporated into the screening process of fleshy-fruited alien plants (Jordaan and Downs 2012; Bitani et al. 2020). Species trait data of fleshy-fruited invasive species are comparable across different regions; therefore, the data can be transferable across regions (Jordaan et al. 2012).

Conclusions

Assessing socio-economic and environmental impacts of fleshy-fruited invasive plant species in South Africa showed that these species pose both ecological and socio-economic impacts. This study also highlighted that the impacts of many fleshy-fruited invasive species are not documented. We recommend management prioritise species with high overall impact scores (*L. camara*, *A. altissima* and *C. camphora*), including species with low overall impact scores, but high impact magnitude for certain mechanisms (*M. alba*, *R. cuneifoliu*, and *S. terebinthifolius*) as the impacts are inevitable. The introduction pathways of these fleshy-fruited invasive plant species need to be identified and managed to prevent their future spread. The present study results showed that different sectors are affected by invasive plant species, emphasising the need for the collaboration of stakeholders in biological invasion management. In South Africa, not all local municipalities have the capacity to effectively implement management strategies to manage invasive species (McLean et al. 2018). Therefore, despite the different mandates for different departments or sectors in South Africa, effective management of invasive plant species requires collaboration at a national and regional level, including and adding a socio-economic dimension to the management strategies to ensure inclusivity and transparency. This study is an important contribution in guiding managing invasive plant species and allocating limited resources in South Africa. We recommend that more research be done to evaluate the impacts, especially socio-economic impacts associated with fleshy-fruited invasive plant species.

References

- Ahmad R, Khuroo AA, Hamid M, Charles B, Rashid I (2019a) Predicting invasion potential and niche dynamics of *Parthenium hysterophorus* (Congress grass) in India under projected climate change. *Biodiversity and Conservation* 28(8–9): 1–26. <https://doi.org/10.1007/s10531-019-01775-y>
- Ahmad R, Khuroo AA, Charles B, Hamid M, Rashid I, Aravind NA (2019b) Global distribution modelling, invasion risk assessment and niche dynamics of *Leucanthemum vulgare* (Ox-eye Daisy) under climate change. *Scientific Reports* 9(1): 1–15. <https://doi.org/10.1038/s41598-019-47859-1>
- Andersen MC, Adams H, Hope B, Powell M (2004) Risk assessment for invasive species. *Risk Analysis* 24(4): 787–793. <https://doi.org/10.1111/j.0272-4332.2004.00478.x>

- Arriaga L, Castellanos AE, Moreno E (2004) Potential ecological distribution of alien invasive species and risk assessment: A case study of buffelgrass in arid regions of Mexico. *Conservation Biology* 18(6): 1504–1514. <https://doi.org/10.1111/j.1523-1739.2004.00166.x>
- Bacher S, Blackburn TM, Essl F, Genovesi P, Heikkilä J, Jeschke JM, Jones G, Keller R, Kenis M, Kueffer C, Martinou AF, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Richardson DM, Roy HE, Saul W-C, Scalera R, Vilà M, Wilson JRU, Kumschick S (2018) Socioeconomic impact classification of alien taxa (SEICAT). *Methods in Ecology and Evolution* 9(1): 159–168. <https://doi.org/10.1111/2041-210X.12844>
- Bartz R, Kowarik I (2019) Assessing the environmental impacts of invasive alien plants: A review of assessment approaches. *NeoBiota* 43: 69–99. <https://doi.org/10.3897/neobiota.43.30122>
- Bitani N, Ehlers Smith DA, Ehlers Smith YC, Downs CT (2020) Functional traits vary among fleshy-fruited invasive plant species and their potential avian dispersers. *Acta Oecologica* 108: e103651. <https://doi.org/10.1016/j.actao.2020.103651>
- Blackburn TM, Essl F, Evans T, Hulme PE, Jeschke JM, Kühn I, Kumschick S, Markova Z, Mrugała A, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Ricciardi A, Richardson DM, Sendek A, Vilà M, Wilson JRU, Winter M, Genovesi P, Bacher S (2014) A unified classification of alien species based on the magnitude of their environmental impacts. *PLoS Biology* 12(5): e1001850. <https://doi.org/10.1371/journal.pbio.1001850>
- Blendinger PG, Villegas M (2011) Crop size is more important than neighborhood fruit availability for fruit removal of *Eugenia uniflora* (Myrtaceae) by bird seed dispersers. *Plant Ecology* 212(5): 889–899. <https://doi.org/10.1007/s11258-010-9873-z>
- Blendinger PG, Martín E, Osinaga Acosta O, Ruggera RA, Aráoz E (2016) Fruit selection by Argentinean forest birds: Influence of fruit functional traits and their temporal variation. *Biotropica* 48(5): 677–686. <https://doi.org/10.1111/btp.12329>
- Burgess KS, Morgan M, Deverno L, Husband BC (2005) Asymmetrical introgression between two *Morus* species (*M. alba*, *M. rubra*) that differ in abundance. *Molecular Ecology* 14(11): 3471–3483. <https://doi.org/10.1111/j.1365-294X.2005.02670.x>
- Charles H, Dukes JS (2008). Impacts of alien invasive species on ecosystem services. In: Nentwig W (Ed.) *Biological Invasions*. Springer, Heidelberg, 218–237.
- Crowley SL, Hinchliffe S, McDonald RA (2017) Invasive species management will benefit from social impact assessment. *Journal of Applied Ecology* 54(2): 351–357. <https://doi.org/10.1111/1365-2664.12817>
- Department of Environmental Affairs (2016) Alien and invasive species list. Government Gazette (No. 40166). Department of Environmental Affairs, Pretoria.
- Estévez RA, Anderson CB, Pizarro JC, Burgman MA (2015) Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conservation Biology* 29(1): 19–30. <https://doi.org/10.1111/cobi.12359>
- Fuster F, Kaiser-Bunbury C, Olesen JM, Traveset A (2019) Global patterns of the double mutualism phenomenon. *Ecography* 42(4): 826–835. <https://doi.org/10.1111/ecog.04008>
- Gaertner M, Den Breeyen A, Hui C, Richardson DM (2009) Impacts of alien plant invasions on species richness in Mediterranean-type ecosystems: A meta-analysis. *Progress in Physical Geography* 33(3): 319–338. <https://doi.org/10.1177/0309133309341607>

- Gosper CR, Vivian-Smith G (2009) The role of fruit traits of bird-dispersed plants in invasiveness and weed risk assessment. *Diversity & Distributions* 15(6): 1037–1046. <https://doi.org/10.1111/j.1472-4642.2009.00599.x>
- Goulson D, Derwent LC (2004) Synergistic interactions between an exotic honeybee and an exotic weed: Pollination of *Lantana camara* in Australia. *Weed Research* 44(3): 195–202. <https://doi.org/10.1111/j.1365-3180.2004.00391.x>
- Hagen BL, Kumschick S (2018) The relevance of using various scoring schemes revealed by an impact assessment of feral mammals. *NeoBiota* 38: 37–75. <https://doi.org/10.3897/neobiota.38.23509>
- Hansen S, Roets F, Seymour CL, Thébault E, van Veen FF, Pryke JS (2018) Alien plants have greater impact than habitat fragmentation on native insect flower visitation networks. *Diversity & Distributions* 24(1): 58–68. <https://doi.org/10.1111/ddi.12656>
- Hawkins CL, Bacher S, Essl F, Hulme PE, Jeschke JM, Kühn I, Kumschick S, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Richardson DM, Vilà M, Wilson JRU, Genovesi P, Blackburn TM (2015) Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT). *Diversity & Distributions* 21(11): 1360–1363. <https://doi.org/10.1111/ddi.12379>
- Hulme PE, Brundu G, Carboni M, Dehnen-Schmutz K, Dullinger S, Early R, Essl F, González-Moreno P, Groom QJ, Kueffer C, Kühn I, Maurel N, Novoa A, Pergl J, Pyšek P, Seebens H, Tanner R, Touza JM, van Kleunen M, Verbrugge LNH (2018) Integrating invasive species policies across ornamental horticulture supply chains to prevent plant invasions. *Journal of Applied Ecology* 55(1): 92–98. <https://doi.org/10.1111/1365-2664.12953>
- Jeschke JM, Bacher S, Blackburn TM, Dick JT, Essl F, Evans T, Gaertner M, Hulme PE, Kühn I, Mrugała A, Pergl J, Pyšek P, Rabitsch W, Ricciardi A, Richardson DM, Sendek A, Vilà M, Winter M, Kumschick S (2014) Defining the impact of non-native species. *Conservation Biology* 28(5): 1188–1194. <https://doi.org/10.1111/cobi.12299>
- Jordaan LA, Downs CT (2012) Comparison of germination rates and fruit traits of indigenous *Solanum giganteum* and invasive *Solanum mauritianum* in South Africa. *South African Journal of Botany* 80: 13–20. <https://doi.org/10.1016/j.sajb.2012.01.007>
- Jordaan LA, Johnson SD, Downs CT (2011a) Digestion of fruit of invasive alien plants by three southern African avian frugivores. *The Ibis* 153(4): 863–867. <https://doi.org/10.1111/j.1474-919X.2011.01157.x>
- Jordaan LA, Johnson SD, Downs CT (2011b) The role of avian frugivores in germination of seeds of fleshy-fruited invasive alien plants. *Biological Invasions* 13(8): 1917–1930. <https://doi.org/10.1007/s10530-011-0013-z>
- Jordaan LA, Johnson SD, Downs CT (2012) Wahlberg's epauletted fruit bat (*Epomophorus wahlbergi*) as a potential dispersal agent for fleshy-fruited invasive alien plants: Effects of handling behaviour on seed germination. *Biological Invasions* 14(5): 959–968. <https://doi.org/10.1007/s10530-011-0131-7>
- Kaufman W, Kaufman SR (2013) Invasive plants: guide to identification and the impacts and control of common North American species (2nd edn.) Stackpole Books, Mechanicsburg.
- Kowarik I, Samuel I (2007) Biological flora of central Europe: *Ailanthus altissima* (Mill.) swing-le. *Perspectives in Plant Ecology, Evolution and Systematics* 8(4): 207–237. <https://doi.org/10.1016/j.ppees.2007.03.002>

- Kumschick S, Bacher S, Dawson W, Heikkilä J, Sendek A, Pluess T, Robinson TB, Ingolf K (2012) A conceptual framework for prioritization of invasive alien species for management according to their impact. *NeoBiota* 15: 69–100. <https://doi.org/10.3897/neobiota.15.3323>
- Kumschick S, Bacher S, Evans T, Markova Z, Pergl J, Pyšek P, Nentwig W (2015) Comparing impacts of alien plants and animals in Europe using a standard scoring system. *Journal of Applied Ecology* 52(3): 552–561. <https://doi.org/10.1111/1365-2664.12427>
- Kumschick S, Vimercati G, De Villiers FA, Mokhatla MM, Davies SJ, Thorp CJ, Rebelo AD, Measey GJ (2017) Impact assessment with different scoring tools: How well do alien amphibian assessments match? *NeoBiota* 33: 53–66. <https://doi.org/10.3897/neobiota.33.10376>
- Laverty C, Nentwig W, Dick JT, Lucy FR (2015) Alien aquatics in Europe: Assessing the relative environmental and socioeconomic impacts of invasive aquatic macroinvertebrates and other taxa. *Management of Biological Invasions : International Journal of Applied Research on Biological Invasions* 6(4): 341–350. <https://doi.org/10.3391/mbi.2015.6.4.03>
- Leung B, Roura-Pascual N, Bacher S, Heikkilä J, Brotons L, Burgman MA, Dehnen-Schmutz K, Essl F, Hulme PE, Richardson DM, Sol D, Vilà M (2012) Teasing apart alien species risk assessments: A framework for best practices. *Ecology Letters* 15(12): 1475–1493. <https://doi.org/10.1111/ele.12003>
- Liu Y, Oduor AM, Zhang Z, Manea A, Tooth IM, Leishman MR, Xu X, Van Kleunen M (2017) Do invasive alien plants benefit more from global environmental change than native plants? *Global Change Biology* 23(8): 3363–3370. <https://doi.org/10.1111/gcb.13579>
- Marciniak B, de Sá Dechoum M, Castellani TT (2020) The danger of non-native gardens: risk of invasion by *Schefflera arboricola* associated with seed dispersal by birds. *Biological Invasions* 22(3): 997–1010. <https://doi.org/10.1007/s10530-019-02139-x>
- McGeoch MA, Spear D, Kleynhans EJ, Marais E (2012) Uncertainty in invasive alien species listing. *Ecological Applications* 22(3): 959–971. <https://doi.org/10.1890/11-1252.1>
- McLean P, Wilson JRU, Gaertner M, Kritzinger-Klopper S, Richardson DM (2018) The distribution and status of alien plants in a small South African town. *South African Journal of Botany* 117: 71–78. <https://doi.org/10.1016/j.sajb.2018.02.392>
- Measey GJ, Vimercati G, De Villiers FA, Mokhatla M, Davies SJ, Thorp CJ, Rebelo AD, Kumschick S (2016) A global assessment of alien amphibian impacts in a formal framework. *Diversity & Distributions* 22(9): 970–981. <https://doi.org/10.1111/ddi.12462>
- Mofu L, Cuthbert RN, Dalu T, Woodford DJ, Wasserman RJ, Dick JTA, Weyl OLF (2019) Impacts of non-native fishes under a seasonal temperature gradient are forecasted using functional responses and abundances. *NeoBiota* 49: 57–75. <https://doi.org/10.3897/neobiota.49.34986>
- Mokotjomela TM, Musil CF, Esler KJ (2013) Do frugivorous birds concentrate their foraging activities on those alien plants with the most abundant and nutritious fruits in the South African Mediterranean-climate region? *Plant Ecology* 214(1): 49–59. <https://doi.org/10.1007/s11258-012-0145-y>
- Mokotjomela TM, Musil CF, Esler KJ (2016) An appraisal of seed enumeration and videographic techniques for determining seed removal rates by birds. *African Journal of Ecology* 54(3): 281–288. <https://doi.org/10.1111/aje.12201>
- Molefe L, Tedder M, Thabethe V, Rushworth I, Downs CT (2020) Role of native avian frugivores in dispersal and germination facilitation of invasive American bramble (*Rubus cuneifolius*) in South Africa. *Biological Invasions* 22: 1109–1120. <https://doi.org/10.1007/s10530-019-02164-w>

- Morgan EC, Overholt WA (2005) Potential allelopathic effects of Brazilian pepper (*Schinus terebinthifolius* Raddi, Anacardiaceae) aqueous extract on germination and growth of selected Florida native plants. *The Journal of the Torrey Botanical Society* 132(1): 11–15. [https://doi.org/10.3159/1095-5674\(2005\)132\[11:PAEOBP\]2.0.CO;2](https://doi.org/10.3159/1095-5674(2005)132[11:PAEOBP]2.0.CO;2)
- Moshobane MC, Mukundamago M, Adu-Acheampong S, Shackleton R (2019) Development of alien and invasive taxa lists for regulation of biological invasions in South Africa. *Bothalia* 49(1): a2361. <https://doi.org/10.4102/abc.v49i1.2361>
- Nel JL, Richardson DM, Rouget M, Mgidi TN, Mdzeke N, Le Maitre DC, van Wilgen BW, Schonegevel L, Henderson L, Neser S (2004) A proposed classification of invasive alien plant species in South Africa: towards prioritizing species and areas for management action: Working for water. *South African Journal of Science* 100: 53–64.
- Nentwig W, Bacher S, Pyšek P, Vilà M, Kumschick S (2016) The generic impact scoring system (GISS): A standardized tool to quantify the impacts of alien species. *Environmental Monitoring and Assessment* 188(5): 1–13. <https://doi.org/10.1007/s10661-016-5321-4>
- Nkuna KV, Visser V, Wilson JR, Kumschick S (2018) Global environmental and socioeconomic impacts of selected alien grasses as a basis for ranking threats to South Africa. *NeoBiota* 41: 19–65. <https://doi.org/10.3897/neobiota.41.26599>
- Novoa A, Kumschick S, Richardson DM, Rouget M, Wilson JR (2016) Native range size and growth form in Cactaceae predict invasiveness and impact. *NeoBiota* 30: 75–90. <https://doi.org/10.3897/neobiota.30.7253>
- Nogueira GS, Seger GD, Boeger MR, Muschner VC (2020) The phenology of *Ligustrum lucidum* (Oleaceae): Climatic niche conservatism as an important driver of species invasion in Araucaria forest. *Biological Invasions* 22(10): 2975–2987. <https://doi.org/10.1007/s10530-020-02302-9>
- Orfinger AB, Gooodding DD (2018) The global invasion of the suckermouth armored catfish genus *Pterygoplichthys* (Siluriformes: Loricariidae): annotated list of species, distributional summary, and assessment of impacts. *Zoological Studies* 57: e7.
- Potgieter LJ, Gaertner M, O'Farrell PJ, Richardson DM (2019) Perceptions of impact: Invasive alien plants in the urban environment. *Journal of Environmental Management* 229: 76–87. <https://doi.org/10.1016/j.jenvman.2018.05.080>
- Pratt CF, Constantine KL, Murphy ST (2017) Economic impacts of invasive alien species on African smallholder livelihoods. *Global Food Security* 14: 31–37. <https://doi.org/10.1016/j.gfs.2017.01.011>
- Pyšek P, Richardson DM (2008) Traits Associated with Invasiveness in Alien Plants: Where Do we Stand? In: Nentwig W (Ed.) *Biological Invasions. Ecological Studies (Analysis and Synthesis)*, vol 193. Springer, Berlin, 97–125. https://doi.org/10.1007/978-3-540-36920-2_7
- Pyšek P, Richardson DM (2010) Invasive species, environmental change and management, and health. *Annual Review of Environment and Resources* 35(1): 25–55. <https://doi.org/10.1146/annurev-environ-033009-095548>
- Pyšek P, Jarošík V, Hulme PE, Pergl J, Hejda M, Schaffner U, Vilà M (2012) A global assessment of invasive plant impacts on resident species, communities and ecosystems: The

- interaction of impact measures, invading species' traits and environment. *Global Change Biology* 18(5): 1725–1737. <https://doi.org/10.1111/j.1365-2486.2011.02636.x>
- R Core Team (2018) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. <http://www.R-project.org/>
- Ramaswami G, Somnath P, Quader S (2017) Plant-disperser mutualisms in a semi-arid habitat invaded by *Lantana camara* L. *Plant Ecology* 218(8): 935–946. <https://doi.org/10.1007/s11258-017-0741-y>
- Rejmánek M (2014) Invasive trees and shrubs: Where do they come from and what we should expect in the future? *Biological Invasions* 16(3): 483–498. <https://doi.org/10.1007/s10530-013-0603-z>
- Reynolds C, Symes CT (2013) Grassland bird response to vegetation structural heterogeneity and clearing of invasive bramble. *African Zoology* 48(2): 228–239. <https://doi.org/10.1080/15627020.2013.11407588>
- Richardson DM, van Wilgen BW (2004) Invasive alien plants in South Africa: How well do we understand the ecological impacts? Working for water. *South African Journal of Science* 100: 45–52.
- Richardson DM, Rejmánek M (2011) Trees and shrubs as invasive alien species-a global review. *Diversity and Distributions* 17(5): 788–809. <https://doi.org/10.1111/j.1472-4642.2011.00782.x>
- Rojas TN, Gallo MC, Vergara-Tabares DL, Nazaro MG, Zampini IC, Isla MI, Blendinger PG (2019) Being popular or freak: How alien plants integrate into native plant-frugivore networks. *Biological Invasions* 21(8): 2589–2598. <https://doi.org/10.1007/s10530-019-01997-9>
- Rumlerová Z, Vilà M, Pergl J, Nentwig W, Pyšek P (2016) Scoring environmental and socio-economic impacts of alien plants invasive in Europe. *Biological Invasions* 18(12): 3697–3711. <https://doi.org/10.1007/s10530-016-1259-2>
- Schirmel J, Bundschuh M, Entling MH, Kowarik I, Buchholz S (2016) Impacts of invasive plants on resident animals across ecosystems, taxa, and feeding types: A global assessment. *Global Change Biology* 22(2): 594–603. <https://doi.org/10.1111/gcb.13093>
- Seebens H (2019) Invasion Ecology: Expanding trade and the dispersal of alien species. *Current Biology* 29(4): R120–R122. <https://doi.org/10.1016/j.cub.2018.12.047>
- Shackleton RT, Witt AB, Aool W, Pratt CF (2017) Distribution of the invasive alien weed, *Lantana camara*, and its ecological and livelihood impacts in eastern Africa. *African Journal of Range & Forage Science* 34(1): 1–11. <https://doi.org/10.2989/10220119.2017.1301551>
- Sharma GP, Raghbanshi AS, Singh JS (2005) Lantana invasion: An overview. *Weed Biology and Management* 5(4): 157–165. <https://doi.org/10.1111/j.1445-6664.2005.00178.x>
- Shivambu TC, Shivambu N, Downs CT (2020) Impact assessment of seven alien invasive bird species already introduced to South Africa. *Biological Invasions* 22(6): 1829–1847. <https://doi.org/10.1007/s10530-020-02221-9>
- Sitzia T, Campagnaro T, Kowarik I, Trentanovi G (2016) Using forest management to control invasive alien species: Helping implement the new European regulation on invasive alien species. *Biological Invasions* 18(1): 1–7. <https://doi.org/10.1007/s10530-015-0999-8>

- SANBI [South African National Biodiversity Institute] (2017) The status report of alien invasive species and their management. South African National Biodiversity Institute, Pretoria. <https://www.sanbi.org/wp-content/uploads/2018/11/National-Status-Report-web-6MB.pdf>
- Thabethe V, Wilson AL, Hart LA, Downs CT (2015) Ingestion by an invasive parakeet species reduces germination success of invasive alien plants relative to ingestion by indigenous turaco species in South Africa. *Biological Invasions* 17(10): 3029–3039. <https://doi.org/10.1007/s10530-015-0932-1>
- Traveset A, Richardson DM (2020) Plant Invasions: The role of biotic interactions—an overview. In: Traveset A, Richardson DM (Eds) *Plant invasions: the role of biotic interactions*. CAB International, Wallingford, 1–25. <https://doi.org/10.1079/9781789242171.0001>
- Turbé A, Strubbe D, Mori E, Carrete M, Chiron F, Clergeau P, González-Moreno P, Le Louarn M, Luna A, Menchetti M, Nentwig W, Pârâu LG, Postigo J-L, Rabitsch W, Senar JC, Tollington S, Vanderhoeven S, Weiserbs A, Shwartz A (2017) Assessing the assessments: Evaluation of four impact assessment protocols for invasive alien species. *Diversity & Distributions* 23(3): 297–307. <https://doi.org/10.1111/ddi.12528>
- van Wilgen BW (2018) The management of invasive alien plants in South Africa: strategy, progress and challenges. *Outlooks on Pest Management* 29(1): 13–17. https://doi.org/10.1564/v29_feb_04
- van Wilgen BW, Reyers B, Le Maitre DC, Richardson DM, Schonegevel L (2008) A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. *Journal of Environmental Management* 89(4): 336–349. <https://doi.org/10.1016/j.jenvman.2007.06.015>
- Verbrugge LNH, de Hoop L, Aukema R, Beringen R, Creemers RCM, van Duinen GA, Hollander H, de Hullu E, Scherpenisse M, Spikmans F, van Turnhout CAM, Wijnhoven S, Leuven RSEW (2019) Lessons learned from rapid environmental risk assessments for prioritization of alien species using expert panels. *Journal of Environmental Management* 249: e109405. <https://doi.org/10.1016/j.jenvman.2019.109405>
- Vilà M, Espinar JL, Hejda M, Hulme PE, Jarošík V, Maron JL, Pergl J, Schaffner U, Sun Y, Pyšek P (2011) Ecological impacts of invasive alien plants: A meta-analysis of their effects on species, communities and ecosystems. *Ecology Letters* 14(7): 702–708. <https://doi.org/10.1111/j.1461-0248.2011.01628.x>
- Vilà M, Gallardo B, Preda C, García-Berthou E, Essl F, Kenis M, Roy HE, González-Moreno P (2019) A review of impact assessment protocols of non-native plants. *Biological Invasions* 21(3): 709–723. <https://doi.org/10.1007/s10530-018-1872-3>
- White RL, Strubbe D, Dallimer M, Davies ZG, Davis AJ, Edelaar P, Groombridge J, Jackson HA, Menchetti M, Mori E, Nikolov BP, Pârâu LG, Pečnikar ŽF, Pett TJ, Reino L, Tollington S, Turbé A, Shwartz A (2019) Assessing the ecological and societal impacts of alien parrots in Europe using a transparent and inclusive evidence-mapping scheme. *NeoBiota* 48: 45–69. <https://doi.org/10.3897/neobiota.48.34222>
- Yazlik A, Pergl J, Pyšek P (2018) Impact of alien plants in Turkey assessed by the Generic Impact Scoring System. *NeoBiota* 39: 31–51. <https://doi.org/10.3897/neobiota.39.23598>
- Zengeya T, Ivey P, Woodford DJ, Weyl O, Novoa A, Shackleton R, Richardson D, van Wilgen B (2017) Managing conflict-generating invasive species in South Africa: Challenges and trade-offs. *Bothalia* 47(2): 1–11. <https://doi.org/10.4102/abc.v47i2.2160>

Supplementary material 1

Table S1

Authors: Nasiphi Bitani, Tinyiko C. Shivambu, Ndivhuwo Shivambu, Colleen T. Downs

Data type: Docx file.

Explanation note: The plant species' functional traits that influence seed dispersal by bird species as identified in Bitani et al. (2020).

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Link: <https://doi.org/10.3897/neobiota.74.83342.suppl1>

Supplementary material 2

Table S2

Authors: Nasiphi Bitani, Tinyiko C. Shivambu, Ndivhuwo Shivambu, Colleen T. Downs

Data type: Docx file.

Explanation note: References used for the data summarised in Table 2.

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